REMARKS

Information Disclosure Statement

Applicant acknowledges Examiner's comments regarding the disclosure of references within the specification and not on a separate list of references submitted as an Information Disclosure Statement. Applicant believes that those references included in the specification, while useful in setting the context for those skilled in the art, were not particularly relevant to the inventive aspects and thus were not added to the Information Disclosure Statement.

Examiner has rejected claims 1-6, 8-9 and 17-24 under 35 USC 102(b) as being anticipated by Ho, US Patent No. 5,895,922. Examiner contends that Ho describes a fluorescence apparatus comprising a laser diode.

Applicant respectfully traverses Examiners rejection. MPEP 2121.01 states "In determining that quantum of prior art disclosure which is necessary to declare an applicant's invention ' not novel' or 'anticipated' within section 102, the stated test is whether a reference contains an 'enabling disclosure'...." *In re Hoeksema*, 399 F.2d 269, 158 USPQ 596 (CCPA 1968). A reference contains an "enabling disclosure" if the public was in possession of the claimed invention before the date of invention. "Such possession is effected if one of ordinary skill in the art could have combined the publication's description of the invention with his [or her] own knowledge to make the claimed invention." *In re Donohue*, 766 F.2d 531, 226 USPQ 619 (fed Cir. 1985).

Contrary to the Examiner's statement that the Ho reference (US 5,895,922) anticipates claims 1-6, 8-9 and 17-24, the Ho reference does not teach a laser diode and thus does not contain an enabling disclosure with respect to a laser diode. The rejection is unsupported by the art and should be withdrawn.

Applicant respectfully wishes to distinguish that a laser diode, as claimed in claims 1, 17 and 20, is not to be confused with a diode-pumped laser as described on page 5 of the enclosed Laser Safety Manual issued by the Radiation Safety Office of Dalhousie University, March 2000 and found at http://is.dal.ca/~ehs/laser.htm. Instead Ho (US 5,895,922) disclosed a He-Cd laser which is a gas laser and which, in this case, is pumped by diode lasers, as described in the attached information found at:

http://stwi.weizmann.ac.il/Lasers/laserweb/Ch-6/C6s2p1.htm,
http://stwi.weizmann.ac.il/Lasers/laserweb/Ch-6/C6s2p2.htm,
http://stwi.weizmann.ac.il/Lasers/laserweb/Ch-6/C6s2p3.htm; and
http://stwi.weizmann.ac.il/Lasers/laserweb/Ch-6/C6s2p5.htm.

Applicant believes that claims 1, 17 and 20 are allowable and claims 2-6, 8, 9, 18, 19 and 21-24 are therefore allowable as being dependant from allowable claims.

Examiner has already found claims 7 and 16 to contain allowable subject matter.

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Examiner has rejected claims 10-15 under 35 USC 103(a) as being unpatentable over Ho, US Patent 5,895,922. Examiner contends that Ho teaches the use of a diode laser with a power of 30mW and that the amount of laser power is considered a design choice driven by many factors such as power availability and the heat dissipation.

Applicant believes that claim 1 from which claims 10-15 are dependant is in condition for allowance and thus claims 10-15 are also in condition for allowance.

Respectfully submitted,

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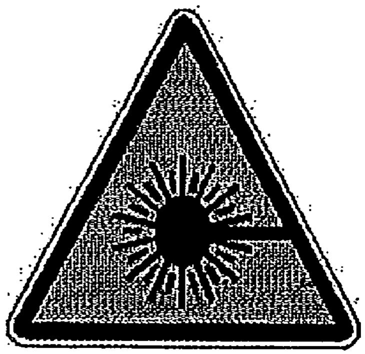
DALHOUSIE UNIVERSITY

LASER SAFETY MANUAL



Issued by the

Radiation Safety Office

March 2000

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A. Basic Laser Operation:

The term ***"LASER"*** is an acronym. It stands for ***"Light Amplification by Stimulated Emission of Radiation"***. Thus, the laser is a device that produces and amplifies light. The mechanism by which this is accomplished was first postulated by Albert Einstein in 1917. The light which the laser produces is unique, for it is characterized by properties which are very desirable, but almost impossible to obtain by any other means.

B. Energy Levels:

Light can be produced by atomic processes, and it is these processes which are responsible for the generation of laser light. Changes in atomic energy levels can lead to the production of laser light.

The relationship between the electrons and the nucleus is described in terms of energy levels. Quantum mechanics predicts that these energy levels are discrete.

C. Radiative Transitions:

Electrons normally occupy the lowest available energy level. When this is the case, the atom is said to be in its ground state. Electrons can, however, occupy higher energy levels, leaving some of the lower energy states vacant or sparsely populated.

One way that electrons can change from one energy state to another is by the absorption or emission of light energy, via a process called radiative transition.

1. Absorption:

An electron can absorb energy from a variety of external sources. From the point of view of laser action, two methods of supplying energy to the electrons are of prime importance. The first of these is the transfer of all energy of a photon directly to its orbital electron. The increase in the energy of the electron causes it to "jump" to a higher energy level; the atom is then said to be in an "excited" state. It is important to note that an electron can accept only the precise amount of energy that is needed to move it from one allowable energy level to another. Only photons of the exact energy acceptable to the electron can be absorbed. Photons of slightly more or less energy will not be absorbed.

Another means often used to excite electrons is an electrical discharge. The energy is supplied by collisions with electrons which have been accelerated by an electric field. The result of either type of excitation is that, through the absorption of energy, an electron has been placed in a higher energy level than the one in which it originally resided.

2. Spontaneous Emission:

The nature of all matter is such that atomic and molecular structures tend to exist in the lowest energy state possible. Thus, an excited electron in a higher energy level will soon attempt to ***de-excite*** itself by any of several means. Some of the energy may be converted to heat.

Another means of de-excitation is the spontaneous emission of a photon. The photon released by an atom as it is de-excited will have a total energy equal to the difference in energy between the excited and lower energy levels. This release of a photon is called spontaneous emission. One example of spontaneous emission is the neon sign. Atoms of neon are excited by an electrical discharge through the tube. They de-excite themselves by spontaneously emitting photons of visible light.

3. Stimulated Emission:

In 1917, Einstein postulated that a photon released from an excited atom could, upon interacting with a second similarly excited atom, trigger the second atom into de-exciting itself with the release of another photon. The photon released by the second atom would be identical in frequency, energy, direction, and phase with the triggering photon. The triggering photon would continue on its way unchanged. Where there was one photon, now there are two. These two photons could proceed to trigger more photon releases through the process of stimulated emission.

If an appropriate medium contains a great many excited atoms and de-excitation occurs only by spontaneous emission, the light output will be random and approximately equal in all directions. The process of stimulated emission, however, can cause an amplification of the number of photons traveling in a particular direction.

A preferential direction is established by placing mirrors at the end of an optical cavity. Thus, the number of photons traveling along the axis of the mirrors increases greatly and ***"Light Amplification by the Stimulated Emission"***, may occur. If enough amplification occurs, ***LASER*** beam is created.

D. Population Inversion:

The process of stimulated emission will not produce a very efficient or even noticeable amplification unless a condition called ***"population inversion"*** occurs. If only a few atoms in several million are in an excited state, the chances of stimulated emission occurring are very small. The greater percentage of atoms in an excited state, the greater the probability of stimulated emission. In the normal state of matter most of the electrons reside in the ground level, leaving the upper excited levels largely unpopulated. When electrons are excited and fill these upper levels to the extent that there is of atoms in the excited state, the population is said to be inverted.

E. Laser Components:

A generalized laser consists of a lasing medium, a pumping system and an optical cavity. The laser material must have a metastable state in which the atoms of molecules can be trapped after receiving energy from the pumping system.

1. Pumping Systems:

- The pumping system imparts energy to the atoms or molecules of the lasing medium enabling them to be raised to an excited or ***"metastable state"*** creating a population inversion. Optical pumping uses photons provided by a source such as xenon gas flash lamp or another laser to transfer energy to the lasing material, in essence pumping atoms from the ground to the excited state. The optical source must provide photons which correspond to the allowed transition levels of the lasing material.

- Collision pumping relies on the transfer of energy to the lasing material by collision with the atoms (or molecules) of the lasing material. Again, energies which correspond to the allowed transitions must be provided. This is often done by electrical discharge in a pure gas or gas mixture in a tube.
- Chemical pumping systems use the binding energy released in chemical reactions to state.

.2. Optical Cavity:

An optical cavity is required to provide the amplification desired in the laser and to select the photons which are traveling in the desired direction. As the first atom or molecule in the metastable state of the inverted population decays, it triggers via stimulated emission, the decay of another atom or molecule which is also in the metastable state. If the photons are traveling in a direction which leads to the walls of the container (usually in the form of a rod or tube), they are lost and the amplification process terminates.

In some cases these photons may actually be reflected at the wall of the rod or tube, but sooner or later they will be lost in the system and will not contribute to the beam.

If, on the other hand, one of the decaying atoms or molecules releases a photon parallel to the axis of the lasing material, it can trigger the

emission of another photon and both will be reflected by the mirror on the end of the lasing rod or tube. The reflected photons then pass back through the material triggering further emissions along exactly the same path which are reflected by the mirrors on the ends of the lasing material. As this amplification process continues, a portion of the radiation will always escape through the partially reflecting mirror. When the amount of amplification or gain through this process exceeds the losses, laser oscillation is said to occur. In this way, a narrow concentrated beam of coherent light is formed.

3. Laser Media:

Lasers are commonly designated by the type of lasing material used. There are four types : ***solid state, gas, dye,*** and ***semiconductor.***

- ***Solid state lasers*** employ a lasing material distributed in a solid matrix. One example is the Neodymium: YAG laser (Nd:YAG). The term YAG is an abbreviation for the crystal - Yttrium Aluminum Garnet which serves as the host for the Neodymium ions. This laser emits an infrared beam at a wavelength of 1.064 μm. Accessory devices that may be internal or external to the cavity may be used to convert the output to visible or ultraviolet wavelength.
- ***Gas lasers*** use a gas or a mixture of gases within the tube. The most common gas laser uses a mixture of Helium and Neon (HeNe), with a primary output of 632.8 nm which is a visible red color. All gas lasers are quite similar in construction and behavior. The carbon dioxide ($CO2$) gas laser radiates at 10.6 μm in the far infrared spectrum. Argon and krypton gas lasers operate with multiple frequency emissions principally in the visible spectra. The main emission wavelengths of an argon laser are 488 and 514 nm.
- ***Dye lasers*** use a laser medium that is usually a complex organic dye in liquid solution or suspension. The most striking feature of these lasers is their "tunability". Proper choice of the dye and its concentration allows production of laser light over a broad range of wavelengths in or near the visible spectra. Dye lasers commonly employ optical pumping although some types have used chemical reaction pumping. The most commonly used dye is Rhodamine 6G which provides tunability over 200 nm bandwidth in the red portion (620 nm) of the spectrum.
- ***Semiconductor lasers*** (diode lasers) are not to be confused with solid state lasers. Semiconductor devices consist of two layers of semiconductor material sandwiched together. These lasers are generally very small physically, and individually of only modest power. The most common diode laser is the Gallium Arsenide diode laser with a central emission of 840 nm.

F. Time Modes Of Operation:

The different time modes of operation of a laser are distinguished by the rate at which the energy is delivered.

- **Continuous wave** (CW) lasers operate with a stable average beam power. In most higher power systems, the operator can adjust the power. In low power gas lasers such as HeNe, the power level is fixed by design and performance usually degrades with long term use.
- **Single pulsed** (normal mode) lasers generally have pulse durations ranging from a few hundred microseconds to a few milliseconds. This mode is sometimes referred to as long pulse or normal mode.
- **Single pulsed Q-switched** lasers are the result of an intracavity delay (Q-switch cell) which allows the laser media to store a maximum of potential energy. Under optimum conditions, emission occurs in single pulses; typically of 10 (-8) second time domain.

These pulses will have high peak powers often in the range of

106 to 109 watts peak.

- **Repetitively Pulsed** or scanning lasers generally involve the operation of pulsed laser performance operating at a fixed or variable pulse rate which may range from a few pulses per second to 20,000 pulses per second. The direction of a CW laser can be scanned rapidly using optical scanning systems to produce the equivalent of a repetitively pulsed output at a given location.
- **Mode Locked** laser operate as a result of the resonant modes of the optical cavity which can effect the characteristics of the output beam. When the phases of different frequency modes are synchronized (locked together) the different modes will interfere with one another to generate a beat effect. The result is a laser output which is observed as regularly spaced pulsations. Lasers operating in this mode locked fashion usually produce a train of regularly spaced pulses, each having a duration of 10 (-15) to

10 (-12) seconds. A mode-locked laser can deliver extremely high peak power, often in the range of 10 (12) Watts peak.

G. Specific Laser Types:

· ***Helium Neon Laser.*** The first CW system was the helium neon (HeNe) gas mixture. Although its first successful operation was at an infrared wavelength of 1.15 µm, the HeNe laser is most well known for operating at the red 633 nm transition. Some HeNe lasers can emit at other wavelengths - 594 nm, 612 nm, 543 nm. Some earlier HeNe lasers were excited by radio frequency discharge but today virtually all HeNe lasers are driven by a small DC discharge between electrodes in the laser tube.

The HeNe laser operates by an excitation of the helium atoms from the ground state. This energy excess is coupled to an unexcited neon atom by a collisional process with the net result of an inversion in the neon atom population. Power levels available from the HeNe laser range from a fraction of a milliwatt to about 75 milliwatts. The HeNe laser is noted for its high frequency stability and single mode operation.

The HeNe laser is one today's the most widely used lasers. Its pencil-thin beam is used in surveying work, to align pipelines, to guide a saw in sawmills, and to align patients in medical x - ray units. It is also used in retail scanners, lecture hall pointers and display devices. Holograms are often made using the coherent light of HeNe lasers.

· ***Argon, Krypton and Xenon Ion Lasers.*** This family of ion lasers provides a source for over 35 different laser frequencies, ranging from near ultraviolet (neon at 322 nm) to near infrared (krypton at 799 nm). It is possible to mix the gases to produce either single frequency or simultaneous emission at ten different wavelengths, ranging from violet to the red end of the spectrum.

The basic design of an ion gas laser is similar to the HeNe. The major difference is that the electrical current flowing in the laser tube will be 10 - 20 amperes; sufficient to ionize the gas. Population inversion is obtained only in the ionized state of the gas. An important feature of these lasers is the very stable high output of up to 20 Watts/CW. Commercial models will normally have a wavelength selector within the cavity to allow operation at any of the available wavelengths. In addition, approximately single frequency operation can be achieved by

placing an etalon inside the optical resonator cavity.

Argon ion lasers produce the highest power levels and have up to 10 lasing wavelengths in the blue-green portion of the spectrum. These lasers are normally rated by the power level produced by all of the six major visible wavelengths from 458 to 514 nm. The most prominent are the 514 and 488 nm lines. Wavelengths in the ultraviolet spectrum at 351 and 364 nm are available by changing resonator mirrors.

To dissipate the large amount of generated heat, the larger argon ion laser tubes are water cooled. Although some lasers have separate heat exchangers, most use tap water.

Simple pulsed versions of argon ion lasers are available. Since the duty cycle is low, the heat energy generated is small, and usually only convective cooling is needed. The average power output may be as high as several watts, though the peak powers can be as high as several kilowatts. Pulse widths are approximately 5 - 50 µseconds, with repetition rates as high as 60 Hz

· ***Carbon Dioxide Laser***. The Carbon dioxide laser is the most efficient and powerful of all CW laser devices. Continuous powers have been reported above 30 kilowatts at the far infrared 10.6 µm wavelength.

An electrical discharge is initiated in a plasma tube containing carbon dioxide gas. CO 2 molecules are excited by electron collisions to higher vibrational levels, from which they decay to the metastable vibrational level. Establishing a population inversion between certain vibrational levels can result in lasing transitions at

9.6 µm.

Although lasing can be obtained in a plasma tube containing CO 2 gas alone, various gases are usually added., including N 2, He, Xe, CO 2 and H2O. Such additives are used to increase the operating efficiency of CO 2 lasers.

Carbon dioxide lasers are capable of producing tremendous amounts of output power, primarily because of the high efficiency. The principal difference between CO 2 and other gas lasers is that the optics must be coated, or made of special materials, to be reflective or transmissive at the far infrared wavelength of 10.6 µm. The output mirror can be made of germanium.

There are three common laser cavity configurations of the CO 2 laser. The first is the gas discharge tube encountered with the discussion of the HeNe laser. Secon is the axial gas flow, where the gas mixture is pumped into one end of the tube and taken out at the other. The gas flow allows for the replacement of the CO 2 molecules depleted by the electrical discharge. Nitrogen is added to the CO 2 to increase the efficiency of the pumping process and transfers energy by collisions. Helium is added to the mixture to further increase the efficiency of the process of pumping and stimulated emissions. The third method is the transverse gas flow. This technique can produce laser emissions at power levels approaching 25 kilowatts.

The CO 2 laser has a strong emission wavelength at 10.6 µm. There is another strong line at 9.6 µm and a multitude of lines between 9 and 11

μm. CO_2 lasers are highly efficient, give high output powers, and applications outdoors can take advantage of low transmission loss atmospheric window at about 10 μm.

· **Nd:YAG Laser Systems**

(YAG), commonly designated Nd: YAG. In addition, other hosts can be used with Nd, such as calcium tungstate and glass.

The Nd: YAG laser is optically pumped either by tungsten or krypton pump lamps and is capable of CW outputs approaching 1000 W at the 1.06 μm wavelength. The ends of the crystal, which are usually in the form of a rod, are lapped, polished, and may be coated to provide the cavity mirrors.

Nd: YAG lasers belong to the class of solid state lasers. Solid state lasers are powerful, rugged and simple to maintain.

Although solid state lasers offer some unique advantages over gas lasers, crystals are not ideal cavities or perfect laser media. Real crystals contain refractive index variations that distort the wavefront and mode structure of the laser. High power operation causes thermal expansion of the crystal that alters the effective cavity dimensions and thus changes the modes. The laser crystals are cooled by forced air or liquids which are used for solid state lasers with high repetition rates.

The most striking aspect of solid state lasers is that the output is not continuous, but consists instead of a large number of often separated power bursts.

Normal mode and Q-switched solid state lasers are often designed for a high repetition rate operation. Usually the specific parameters of operation are dictated by the application.

For example, pulsed YAG lasers operating 1 Hz at 150 joules per pulse are often used in metal removal applications. As the repetition rate increases, the allowable exit energy pulse decreases.

· **Excimer Lasers**

People have searched for high power ultraviolet lasers for over 25 years. Theoretically, such a laser could produce a focused beam of submicrometer size and be useful in laser microsurgery and microlithography. Excimer lasers operate using reactive gases such as chlorine and fluorine mixed with inert gases such as argon, krypton or xenon. The various gas combinations, when electrically excited, produce a pseudo molecule, called a ***dimer*** with an energy level configuration that causes the generation of a specific laser wavelength emission which falls in the UV spectrum as illustrated below:

Laser Media	Wavelength (µm)
Argon Fluoride	193
Krypton Chloride	222
Krypton Fluoride	248
Xenon Chloride	308
Xenon Fluoride	351

Excimer laser reliability has made significant strides over the past several years. Systems operating at average powers from 50 - 100 watts are now commercially available. A typical excimer operates in repetitively pulsed mode of 30 - 40 ns pulses at pulse rates up to 50 Hz with pulse energies of 1 - 2 joules/pulse. Some systems use x-rays to preionize the excimer laser's gas mixture so as to enhance lasing efficiency and increase the overall output power.

Until fairly recently, excimer lasers were more commonly found in the research laboratory where they are used as a specific UV source. In other cases, serve as a"pumping" or exciting source to generate visible laser emissions. In the latter case, the excimer's UV output is directed into a tunable dye laser or Raman shifter module and converted into a modestly high power visible frequency emission.

Excimer lasers are now making the transition from the lab to the production area for a few unique uses in industry or in the operating room for exploratory surgical applications.

· **Semiconductor Diode Lasers:**

The semiconductor or diode injection laser is another type of solid state laser. The energy level scheme is constructed by charge carriers in the semiconductor. They may be pumped optically or by electron beam bombardment, but most commonly, they are pumped by an externally applied current. Although all of these devices operate in the infrared region, visible laser diodes are being made today. A useful feature is that many can be tuned by varying the applied current, changing temperature, or by applying an external magnetic field.

6.1.3 Helium-Cadmium Laser

Helium-Cadmium lasers can be categorized among either:

- **Metal vapor lasers** - Cadmium is a metal, the lasing action in Helium Cadmium laser occurs between energy levels of **Cadmium ions**, so the **lasing medium is ionized metal vapor.**
- **Ion gas lasers** - The properties of Helium-Cadmium laser are similar to those of **Helium-Neon laser** which is a neutral atom gas laser.

The He-Cd laser is a gas laser, and the metal Cadmium can be transform into the gas phase by heat.

The excitation to the upper laser level of the Cadmium atoms in the gas is similar to the excitation process of the Neon gas in a **Helium-Neon laser**: Helium atoms are excited by collisions with accelerated electrons, and than they pass their energies to Cadmium atoms by collisions.

The transitions in Helium-Cadmium laser are between energy levels of **singly ionized Cadmium atoms**, and about **twelve lines are available**. These wavelengths are in the **shorter wavelength region, violet and Ultra-Violet (UV)**. Thus, the main application of the He-Cd laser is in the optics laboratory, for fabricating holographic gratings.

The **practical problem** in Helium-Cadmium laser is to maintain homogeneous distribution of the metal vapor inside the electrical discharge tube. The ions are attracted to the cold windows at the ends of the cavity. In order to prevent coating of the windows with Cadmium, cold traps are put before the laser windows.

Lasing action in a Helium-Cadmium Laser:

The Cadmium metal is heated to a temperature of 250^0C, to create the appropriate vapor pressure.
The Cadmium vapor pressure of a few millitorr is added to Helium gas at a pressure of 3-7 millitorr.
Since Helium is a noble gas, its excitation energy is very high (24.46 [eV]) compared to the Cadmium which is a metal with low excitation energy (8.96 [eV]). Thus in He-Ne laser the Helium remains electrically neutral, and fills the cavity of the tube, while the **positive Cadmium atoms are moving toward the negative cathode.**

In the design of the tube of Helium-Cadmium laser most of the effort is to reduce to a minimum the amount of Cadmium ions on the cathode. The best He-Cd lasers loose about 1 [g] Cadmium metal for 1,000 hours of operation of the laser.

For comparison, the gain and power output of the main two lines of He-Cd laser are higher than for the He-Ne laser, but less than for the $Ar^{\pm}$ laser.

Characteristics of He-Cd lasers:

- **Output wavelengths**: Blue light 0.4416 [μm], and Ultra-Violet (UV) light 0.3250 [μm].
- **Maximum output power**: 150 [mW] in the blue line, and 50 [mW] at UV.
- **Maximum total efficiency**: in the blue line 0.02%, and in the UV 0.01%.
- **Spectral width**: 0.003 [nm] (about 5 [GHz]), and **coherence length**: about 10 [cm].
- **Distance between two longitudinal modes**: about 200 [MHz].

Optically Pumped Solid State Lasers

The active medium in these lasers is a crystal or glass.

The shape of the active medium is usually a rod **with circular or square cross section.**

The pumped beam usually enter the active medium via its surface area along the rod, while the laser radiation is emitted through the ends of the rod. The ends of the rod are usually at right angles to the rod axis, and are optically polished.

Solid state lasers emit radiation in either **pulsed mode** or in **continuous mode**.

The pump lamps for pulsed lasers are usually Xenon (or Krypton) flash lamps, in which a low pressure gas is contained within quartz tube.

The pump lamps for pulsed lasers are usually Xenon (or Krypton) flash lamps, in which a low pressure gas is contained within quartz tube.

The pump lamps for continuous lasers are usually Halogen lamps, or high pressure Mercury discharge lamps .

Diode Pumped Solid State Lasers (DPSSL).

During the last few years, with the new developments of **diode lasers** (see section 6.3) at high powers, a new pumping method is being developed for solid state lasers.

Instead of broad spectrum pumping source, Diode Lasers are used as pumping sources.

The wavelength in these diode lasers can be adjusted to fit the absorption spectrum of the active medium.

These diode lasers are very efficient sources, and almost all their light is absorbed by the active medium. Thus, very little energy is lost (converted into unwanted heat).

These solid state lasers which are pumped by diode lasers are called: **Diode Pumped Solid State Lasers (DPSSL).**
